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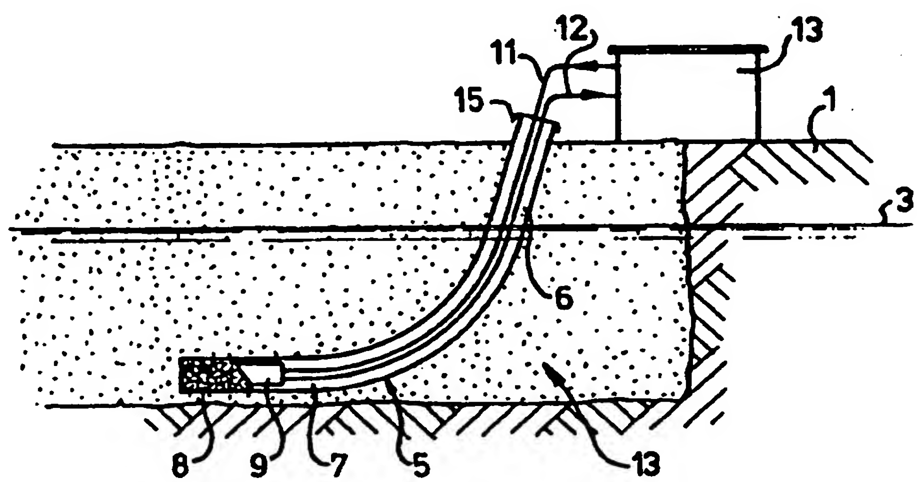

(57) Abstract

The invention relates to a method of consolidating watery ground, in particular relatively impermeable watery ground. A pump (9) to which a pumping liquid is fed is arranged in a drainage element (13) below the groundwater table. The groundwater and/or the gas present in the subsoil is discharged by means of the pumping liquid. A very quick and efficient consolidation of the ground can be obtained as a result. The pump (9) preferably comprises a venturi pump. The drainage element (13) may comprise a vertically directed wall of sand in which a tubular element containing the pump is placed.

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sand. Furthermore, the maximum attainable underpressure can be applied immediately without the risk of the subsoil to be treated slipping. As a result, this consolidation method allows a predetermined level of consolidation to be achieved more quickly than using a top load by means of an earth body. Furthermore, this method is effective since the pressure difference applied is of equal magnitude in three main directions.

A drawback of the above-described consolidation method is that it is not possible to achieve an underpressure in the drainage layer situated at the surface of greater than 6-7 metres water column. The underpressure in the water-saturated ground decreases by 0.1 bar per metre of depth, so that at a depth of 6 metres atmospheric pressure prevails. Furthermore, gas and/or air is released at many locations in the ground owing to the pressure reduction in the groundwater. This formation of gas means that the volume to be pumped off increases, which impairs the efficiency of the water removal system.

A further drawback of the above-described method is that all the vertical drainage channels are connected together via the drainage layer, so that the system as a whole is extremely sensitive to leakage. It is therefore frequently difficult in practice to maintain the desired underpressure for a relatively long period of time. The entire system is sensitive to a single leak. This is even more important when it is considered that the vertical drainage channels in the conventional methods are used in numbers of 2000 to 10,000 per hectare.

One object of the present invention is to provide a method of consolidating watery ground in which a permanent reduction in the volume of the ground can be brought about in an effective and rapid manner. Another object of the present invention is to provide a system by means of which a relatively great underpressure can be applied in the ground. A further object of the present invention is to provide a method of this kind in which a relatively small number of easy-to-operate pumps can be used, which pumps are relatively unsusceptible to maintenance, are not adversely affected by the groundwater level, and can be used at a great number of different depths. To this end, the method according to the invention comprises the following steps:

- introducing a drainage element into the ground to below the

Method of consolidating watery ground

The invention relates to a method of consolidating watery ground, in particular to the forced consolidation of relatively impermeable, compressible soil strata.

The accelerated drainage of clay and peat strata is known by firstly providing vertical drainage channels therein and then subjecting these layers to a load. The load applied exerts an excess pressure on the interstitial water in the clay or peat strata. The vertical drainage channels ensure a considerably improved discharge of the groundwater. This drainage method also means that water in the ground can flow in the horizontal direction towards the drainage channels, as a result of which optimum use is made of any stratification in the soil structure. In the case of a stratified soil structure, the permeability of the ground in the horizontal direction is as a rule greater by a factor of 10 than that in the vertical direction. When consolidating the soil stratum in this way, the ground is subjected to loading in a controlled manner. Care is taken here not to apply the load so quickly and/or to make it so high that the earth body forming the load can slide. Due to the fact that it is necessary to maintain the stability of the load, the rate at which drainage can be forced is limited.

In the abovementioned method of consolidating, a horizontal drainage layer can be arranged at ground level above the top of the vertical drainage channels. This drainage layer generally comprises a layer of sand having a thickness of, for example 0.3 metres or more. This layer absorbs the groundwater which leaves the ground via the drainage channels. A specific embodiment is that in which this layer is covered by a film whose edges are buried in the ground to below the groundwater table. As a result it becomes possible to apply an underpressure in the drainage layer and in the vertical drainage channels which adjoin the drainage layer. Due to the pressure difference between the underpressure in the drainage system and the atmospheric pressure outside the latter, a load is formed on the subsoil. This load provides the initial impetus to the forced consolidation process. The advantage of applying an underpressure is that the latter can be applied and removed more easily than a thick layer of filler

groundwater table,

- placing a pump in the drainage element below the groundwater table,
- feeding a pumping liquid to the pump through a feedline,
- and discharging the pumping liquid and at least the groundwater present around the pump by entraining the groundwater with the pumping liquid through the discharge line.

By using a pump in which the pumping action is obtained by means of the pumping liquid, this pump can be arranged at any desired position in the drainage element. By means of the pump according to the invention, the groundwater is pressed upwards instead of being sucked upwards.

With the aid of a pump according to the invention, such as a venturi pump, an underpressure of at least 9 metres water column can be generated. If the venturi pump according to the invention is placed at a depth of 5 metres, the effect for a groundwater level which lies one metre below ground level is an underpressure of 13 metres water column. In the known methods, an underpressure of not more than one metre water column is obtained. Due to the fact that a great pressure difference can be generated using the venturi pump according to the present invention, sufficient compression of the ground can be achieved within a relatively short time.

In the case of drainage elements which are open at the top, so that air can enter, the water level is lowered by using the pump according to the invention. Due to the lowering of the groundwater level, the load increases owing to the ground coming above water level and the absence of the upwards force of the groundwater thereon, as a result of which consolidation is achieved.

In the case of drainage elements which are closed off from the environment by an upper cover, so that the access of air is prevented, an underpressure is achieved. This underpressure provides the load on the soil stratum which ensures consolidation.

"Drainage element" is intended to mean a structure which is arranged in the ground and has a greater porosity than the surrounding soil stratum. The drainage element may, for example, comprise a shaft having a diameter of, for example, 10 cm or more. This shaft may be filled with sand or another relatively porous

material, such as for example rubble or gravel. The drainage element may also be formed by a vertical wall made of relatively permeable material and having a length of several hundred metres, a depth of between 1 and 7 metres and a width of between 5 cm and 25 cm. A strip of filter cloth which is inserted vertically into the ground may also be used as drainage element.

If the subsoil itself is relatively permeable, such as a sandy subsoil, the drainage element may, for example, comprise only a tubular element containing the pump according to the invention. With this type of soil, the groundwater level will fall and, in view of the low compressibility, a small degree of consolidation will be obtained.

Pumps operating with a pumping liquid are of extremely simple design, since they do not comprise any mechanically moving parts and can be of relatively small size, such as for example having a diameter of about 10 centimetres and a length of about 20 centimetres. As a result, pumps of this kind are relatively unsusceptible to maintenance and can easily be arranged in, for example, a relatively tight drainage shaft or a relatively narrow tubular element, bends in the latter forming no obstacle to the introduction. Furthermore, it is possible using pumps of this kind to achieve a relatively high reduction in pressure which may be 50% higher than is usual with conventional motor-driven pumps. This results in greater efficiency ad the desired degree of consolidation can be achieved more rapidly than in the known methods or a higher degree of consolidation can be achieved in the same time.

Preferably, the pump is formed by a venturi pump with a pump capacity of at least 1 m^3 per hour, preferably between 1 and 10 m^3 per hour.

Preferably, both gas and the groundwater around the pump are removed via the discharge line by being entrained with the pumping liquid. In general, the pump will be used firstly to pump off gas which lies above the water. In a following stage, a large amount of gas and a small amount of water is pumped off and finally a mixture of gas and water is pumped away, since gas is continuously released as the underpressure rises and is continuously entrained. By removing not only the water from the ground but also the gas, such as air, by means of the pump, a very

rapid and effective settlement of the ground can be brought about. It has been found that by removing both water and gas from a watery subsoil the settlement time can be accelerated by a factor of 2 to 8, for example a settlement time of 1 to 3 months, compared to settlement times of 6 months to 1 year as in the known accelerated consolidation methods. The method according to the invention is particularly suitable for quickly making building sites and traced-out roads suitable for construction and for ensuring that on completion the subsidence of the ground level which is still to be expected is as small as possible, and preferably negligible. In that event, cables and pipes, but also railways and paved or asphalted surfaces or roads, streets, squares, pavements, gardens and the like will no longer be subject to any settlement once a treated area has been completed. This results in a considerable saving on maintenance costs.

Using the consolidation method according to the invention also makes it possible to consolidate strips of ground where streets and/or gardens are situated while carrying out building work around these strips which are being consolidated. Since the building work on the compressible ground involves driving piles, consolidation will not be possible at the location of the building work itself.

An essentially airtight seal may be arranged at the feed opening of the drainage element, such as a sand-filled shaft, or a tubular element. If a tubular element is arranged in the ground with a closed tube wall and a sealed tube end which is positioned in the ground and is provided with perforations, which tubular element contains the pump, the seal can be formed by a cap over that end of this tubular element which is situated above the ground. A cap of this kind placed over the blind part of the said tubular element is essential for obtaining sufficient underpressure.

Preferably, a multiplicity of drainage elements is arranged in the ground so as to achieve effective drainage. Preferably, each drainage element surrounds a respective tubular element in which a pump is positioned. It is thus possible, for example, to consolidate a strip of 100 by 5 metres using one drainage element and one pump according to the invention arranged therein, so that only 20 drainage elements and pumps are required

per hectare of land. For a settlement rate of 30 mm/day, it is then necessary to discharge 15 m^3 of water/gas under atmospheric pressure. Together with this amount there is also leakage water which flows in through the ground from the sides or the bottom and/or precipitation on the surface of the ground. A pump capacity of 1-3 m^3 per hour is sufficient to consolidate the ground.

If, in the event of their being a multiplicity of drainage elements, each drainage element is provided with its own pump, this has the advantage that in the event of an excess of gas being sucked in by one pump, for example due to the fact that the seal has developed a leak or a pump is malfunctioning, this has no adverse effect on the other pumps, which are independent thereof. Preferably, each pump is provided with a monitoring device for determining the pressure difference across the respective pump. As a result it is possible to check efficiently that this pump is not sucking up an excess of air and that there is no need to replace the seal.

In the case of known pumps, a problem frequently encountered is that the iron present in the groundwater blocks the pumps and the lines by flocculation. This can be prevented in an expedient manner in the present pumping device by adding an acid to the pumping liquid.

An embodiment of the method according to the present invention will be explained in more detail with reference to the appended drawing, in which:

Figure 1 shows a diagrammatic depiction of a pump according to the invention placed in the subsoil, and

Figure 2 shows a diagrammatic detailed depiction of a venturi pump according to the invention.

Figure 1 shows a subsoil 1 having a groundwater table 3. A tubular element 5 with a vertical section 6 and a horizontal section 7 is arranged in the subsoil 1. The tube 5 is of a "blind" design in the vertical section 6 and is essentially impervious to water and air. The blind section of the tube 5 may, for example, be 25 m long. That end of the tube 5 which is positioned in the subsoil, having a diameter of, for example, 10 cm, is provided with perforations 8, through which the groundwater can penetrate into the tube 5. A venturi pump 9 having a flexible feedline 11 and a flexible discharge line 12 is positioned in the tube 5. A

pumping liquid, such as for example water, is fed through the feed-line 11, via a centrifugal pump 13, to the venturi pump 9 at a pressure of a number of atmospheres, for example 10 atmospheres excess pressure. Due to the pumping liquid, an underpressure is formed on the feed side of the venturi pump 9 and liquid and gas are entrained by the pumping liquid via the discharge line 12 at a lower pressure and higher flow rate compared to the feedline 11. Using the venturi pump 9, it is possible to remove between 1 and 10 m^3 of water and/or gas per hour from the subsoil 1.

As shown in Figure 1, the tube 5 is situated in a drainage element 13. The drainage element 13 extends, for example, to a depth of 7 metres below the surface of the ground 1 and has a dimension perpendicular to the plane of the drawing of about 25-30 centimetres. The drainage element 13 is filled, for example, with a porous material such as sand or rubble. Preferably, a number of drainage elements 13 are arranged parallel to one another in the subsoil at a mutual distance of, for example, 5 metres, so that, for example, each strip of 100 m x 5 m comprises a drainage element. Each drainage element is provided with its own venturi pump 9. It is also possible to arrange a plurality of venturi pumps 9 in a single drainage element, for example at both ends thereof. The water from the subsoil 1 will flow to the closest drainage elements 13 and is discharged via the perforations 8 in the tube 5. A seal 15, in the form of, for example, a plastic cap, is arranged at the top of the tube 5, preventing air from being able to pass to the venturi pump 9 along the top of the drainage shaft. Using the drainage structure according to the invention, each strip of 100 m x 5 m can be settled at a rate of 30 mm per day.

A top load can be applied to the subsoil 1 in the form of an additional layer of earth or sand and/or water. In that event, the tubes 5 can easily be lengthened to above the ground covering in order to be able to place the pumps 9 with their feedlines 11 and discharge lines 12 in the tubes 10 and to be able to recover them on completion.

Preferably, the above-described drainage structure is used in relatively impervious subsoils, such as clay or peat. The drainage method which involves placing a venturi pump in a drainage shaft or tube can also be used for subsoils of greater

permeability, such as for example sand. In this case, it is not necessary to use a further drainage element in addition to a tubular drainage element.

Figure 2 shows a diagrammatic depiction of a venturi pump 9 according to the present invention. The pumping liquid B is fed through an opening 19 in an internal tube 20. The pumping liquid, which passes out of the internal tube 20 at high speed via a nozzle 22, results in an underpressure at the feed opening 17 of the pump 9. As a result, groundwater and gas present around the pump are sucked into the feed opening 17 via the direction of the arrow A. The pumping liquid B and the gas and/or water A sucked in are discharged via the discharge opening 18 of the pump. A suitable venturi pump has a length of 320 millimetres and a maximum width of 70 millimetres. Pumps of this kind are produced by Grundfoss under model number 900216. The maximum discharge of the pumps is 2.5 m^3/hour. In a pump of this kind, the connections for the feedline 11 and the discharge line 12 are oriented next to one another in the same direction. The feed opening 17 lies on the opposite side. Using the relatively rigid lines, the venturi pump can be inserted, with the feed opening 17 at the front, into a tube with an internal diameter of 10 cm.

Advantageously, an acid can be added to the pumping liquid B for dissolving the iron present in the groundwater, so that the venturi pump 9, the feedline 11 and discharge line 12 do not become blocked by this iron.

Some of the discharged water A + B can be reused as pumping liquid B.

CLAIMS

1. Method of consolidating watery ground (1) with a groundwater table (3), comprising the following steps:
- introducing a drainage element (5, 13) into the ground (1) to below the groundwater table,
- placing a pump (9) in the drainage element (5, 13) below the groundwater table (3),
- feeding a pumping liquid to the pump (9) via a feedline (11),
- and discharging the pumping liquid and at least the groundwater present around the pump by entraining the groundwater with the pumping liquid via a discharge line (12).

2. Method according to Claim 1, characterized in that the pump (9) comprises a venturi pump with a pump capacity of at least 1 m^3 per hour, preferably between 1 and 10 m^3 per hour.

3. Method according to Claim 1 or 2, characterized in that both gas and the groundwater around the pump (9) are removed via the discharge line (12) by entrainment together with the pumping liquid.

4. Method according to Claim 3, characterized in that an essentially airtight seal (15) is arranged around a feed opening of the drainage element.

5. Method according to one of the preceding claims, characterized in that the drainage element (13) comprises a tubular element (5) with one tube end positioned in the ground, the tube wall being provided with perforations (8) in the region of the end which is positioned in the ground.

6. Method according to one of the preceding claims, characterized in that the drainage element (13) comprises a vertically directed wall made of a porous material, in which wall the pump (9) is arranged.

7. Method according to Claims 5 and 6, characterized in that the drainage element (13) is formed by digging a trench in the subsoil (1), placing the tubular element (5) in the trench and filling the trench with a porous material, such as sand.

8. Method according to one of the preceding claims, characterized in that the drainage element has a width of between 5 cm and 40 cm, a length of between 1 metre and 500 metres and a depth of between 1 and 10 m.

9. Method according to one of the preceding claims, characterized in that a multiplicity of drainage elements is arranged in the ground, each having its own pump, such as not more than 100 pumps per hectare, preferably not more than 20 pumps per hectare.

10. Method according to Claim 6, 7, 8 or 9, a number of drainage elements being placed parallel to one another with a mutual spacing of between 0.5 m and 5 m, preferably about 2.5 m.

11. Method according to one of the preceding claims, characterized in that the pump, or a pumping-liquid feed unit connected thereto, is provided with a monitoring device for determining the pressure difference across the respective pump.

12. Method according to one of the preceding claims, characterized in that a solvent is fed to the pumping liquid, such as for example an acid.

Fig-1

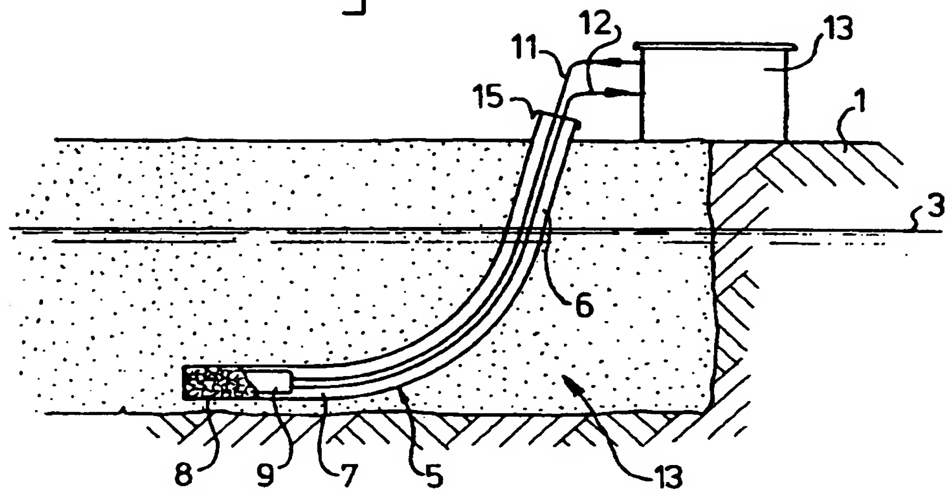
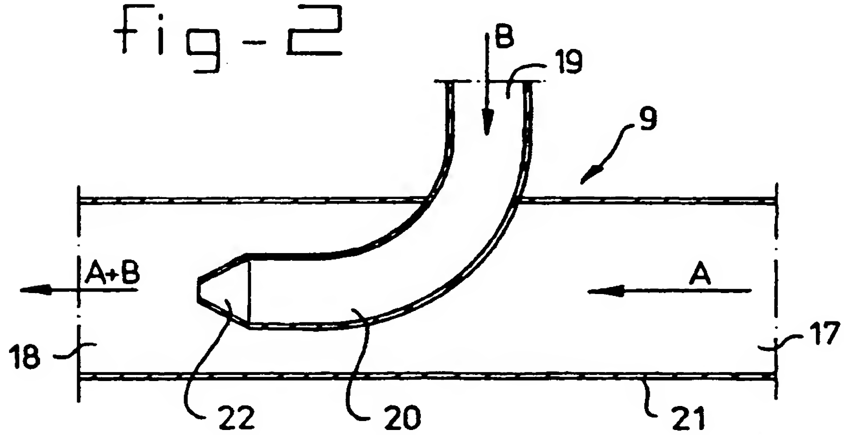


Fig-2



INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E02D3/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E02D E02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	FR 2 663 373 A (COGNON) 20 December 1991 see page 2 - page 9; figures	1-5
A	US 4 927 292 A (JUSTICE) 22 May 1990 see column 3, line 6 - column 6; figures	1,5-7
A	EP 0 677 616 A (KONINKLIJKE WEGENBOUW STEVIN) 18 October 1995	
A	WO 92 18702 A (BAYER AG) 29 October 1992	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 September 1997	17.10.97

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Information on patent family members

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